2001 Users Group Conference

Submerged Wakes in Littoral Regions

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Project Overview

Turbulent Wakes from Submerged Vehicles Operating in Coastal Regions

Complex Phenomena Requiring Ultra-Large Scale Computations

Maneuvering Vehicles Generate Complex Wake Patterns

Hull and Appendage Vortex Structures **Propulsor Wakes**

Very Complex Geometry, Dominant Flow Physics is Localized

Vehicle Wakes Interact with Difficult Coastal Environment

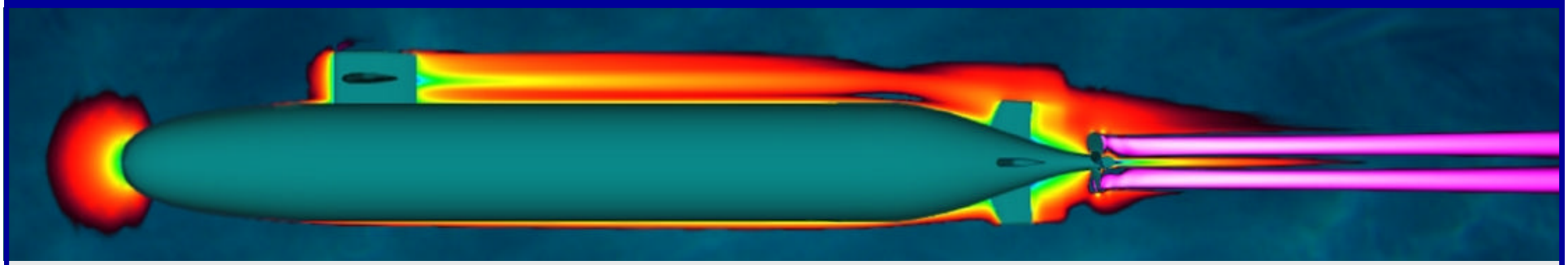
Shallow Water **Stratification** **Wave Motion** **Shear** **Currents**

Simple Geometry, Very Complex Turbulence Physics

UnRANS Predictions for Vehicle Maneuvering

LES Simulations for Far-Field Wake Structures

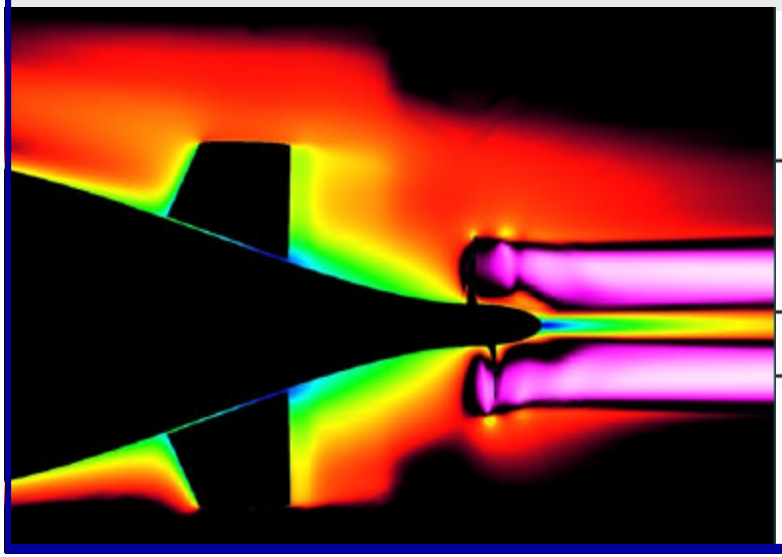
Interactions of Vehicle Motion with Wake Signatures

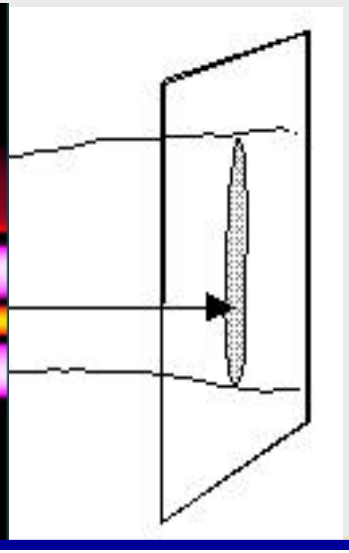


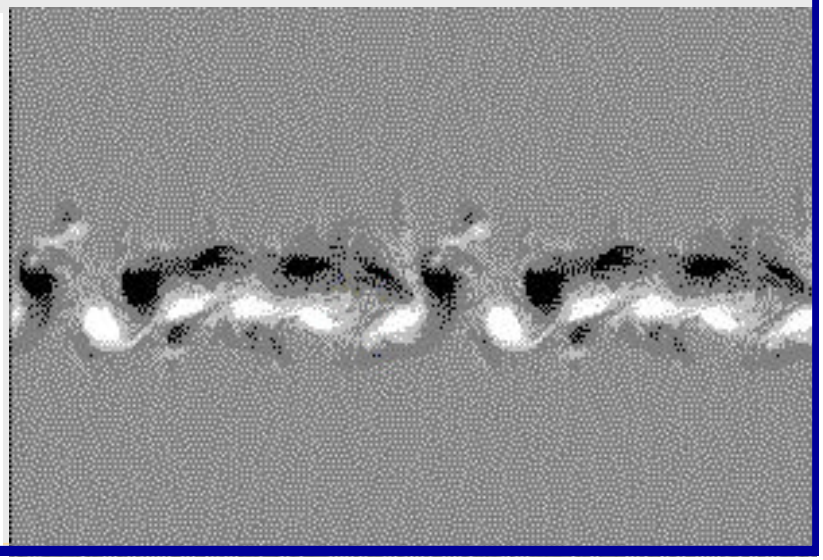
Near-Field Wakes from Maneuvers

Far-Field Wakes in Littoral Environment

UnRANS **Interface** **LES**







Background: Previous Challenge Project on Submarine Maneuvering

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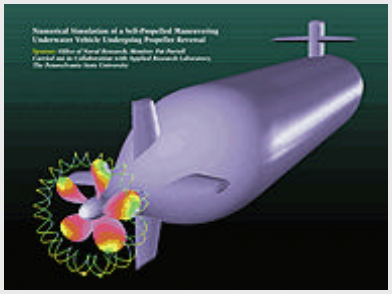
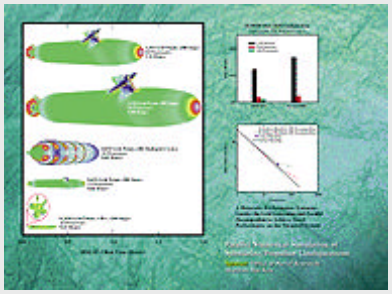


February 1997



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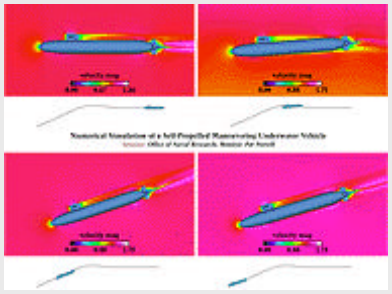

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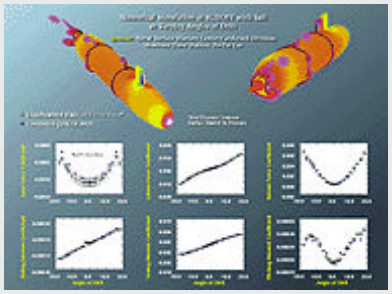
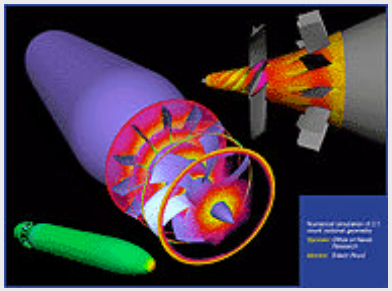


April 1998



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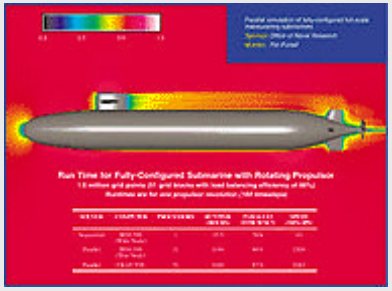

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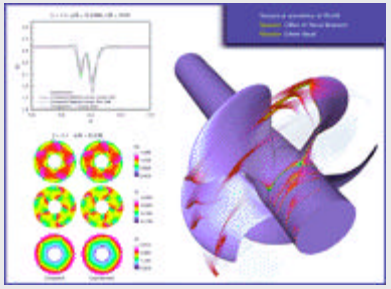

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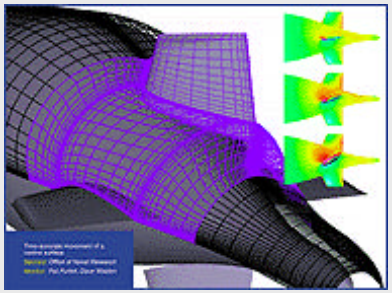

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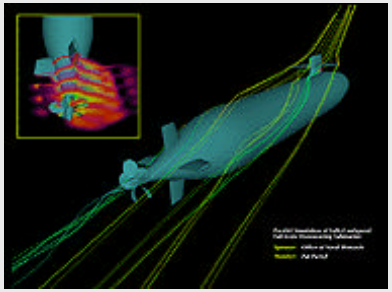

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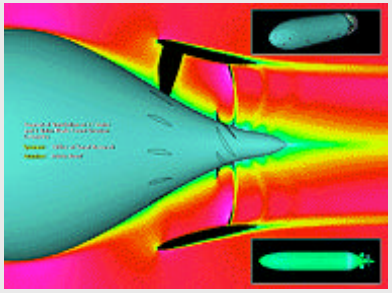

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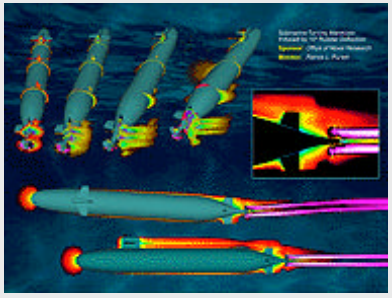
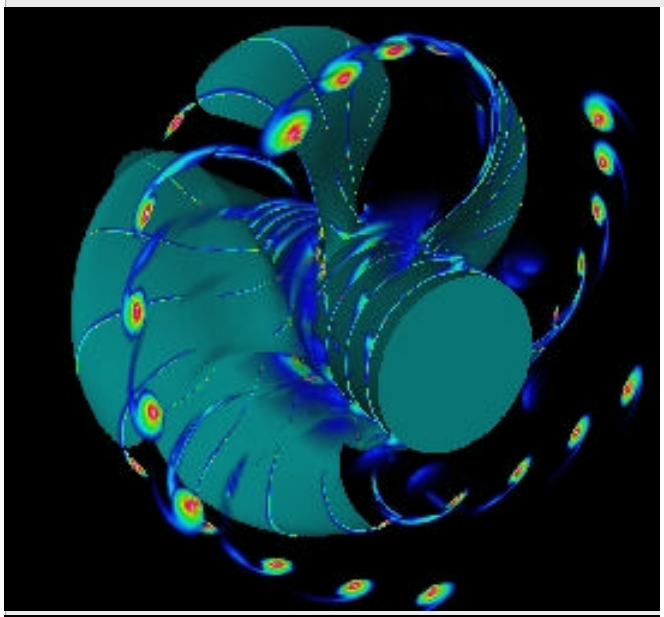
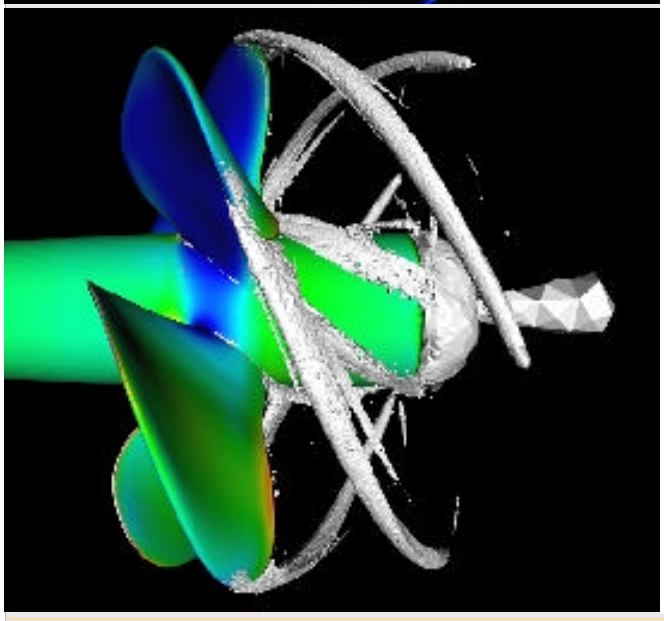
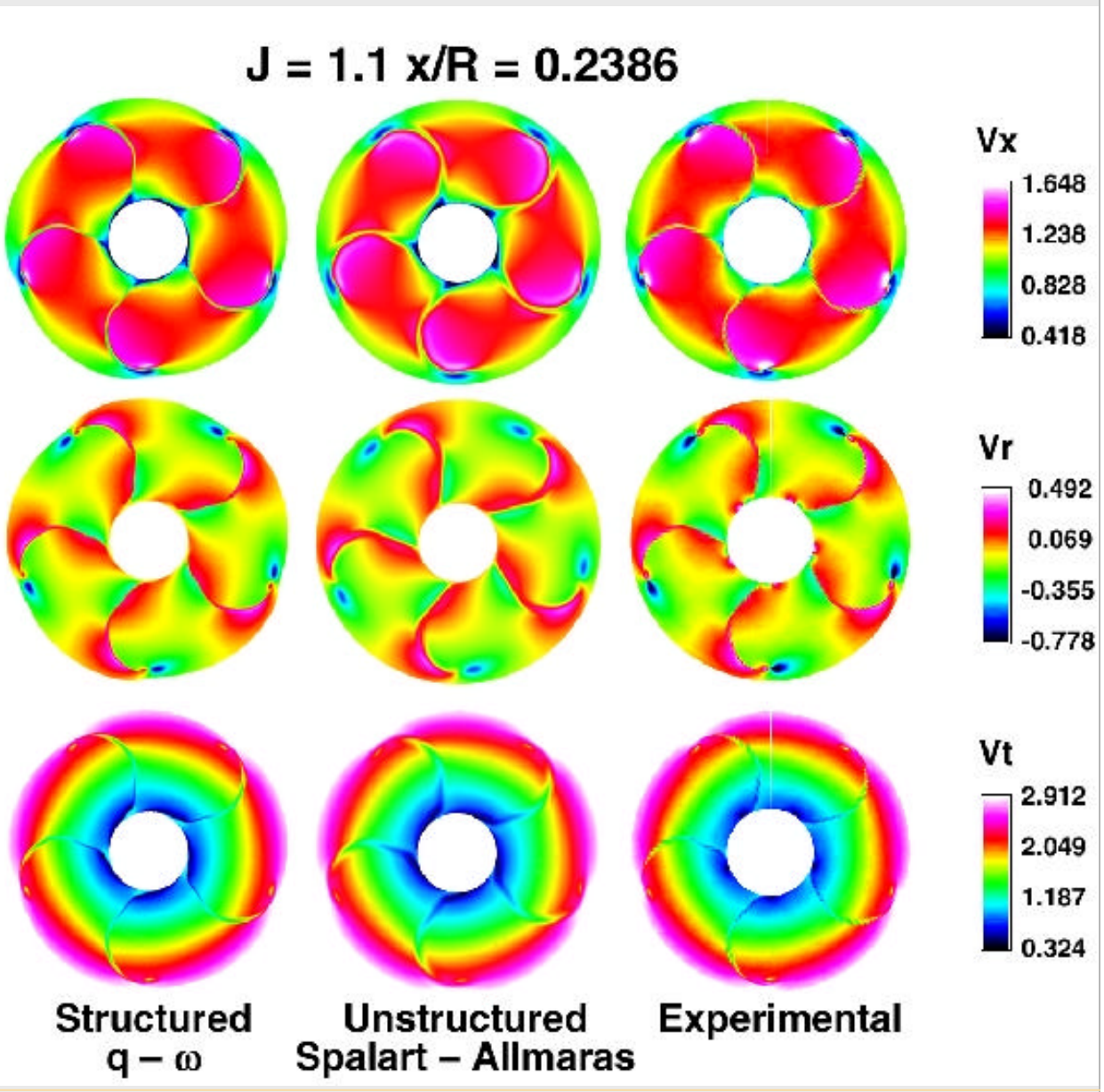


April 2000

Detailed Validation of Propeller Vortices

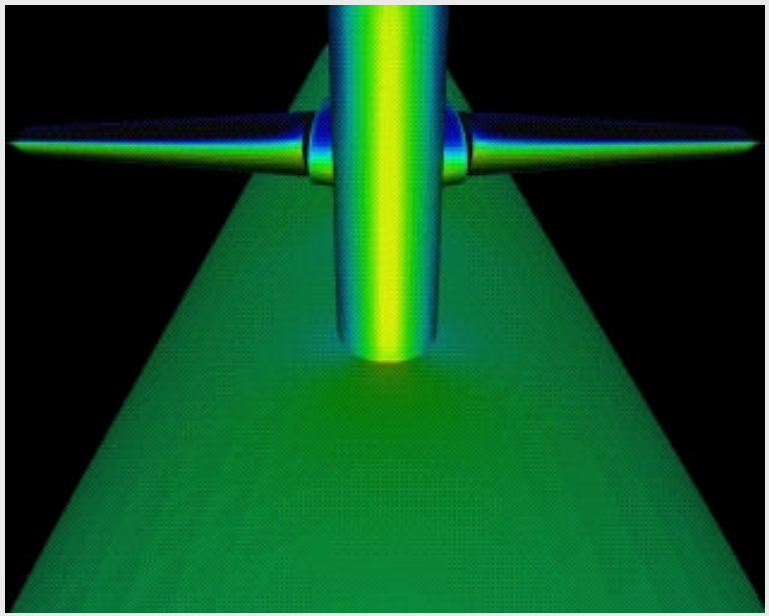


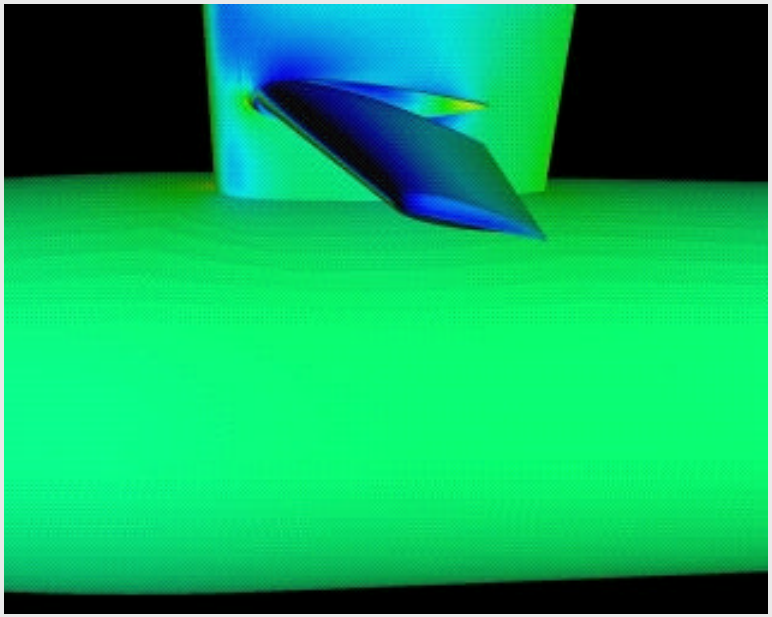


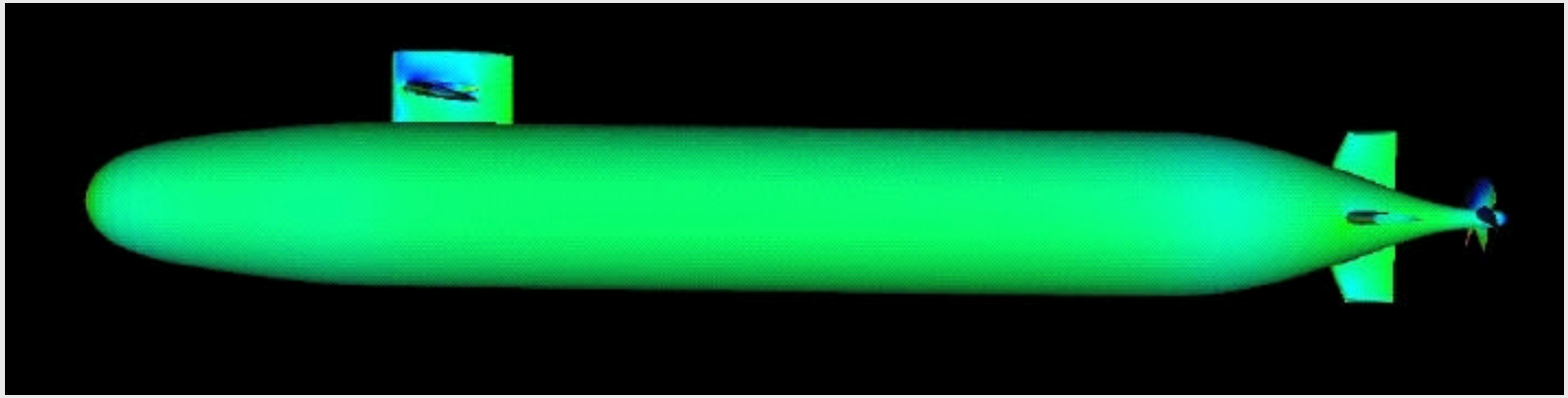


Sailplane-Induced Rising Maneuver

Appended SUBOFF Hull with Sailplane Pedestals

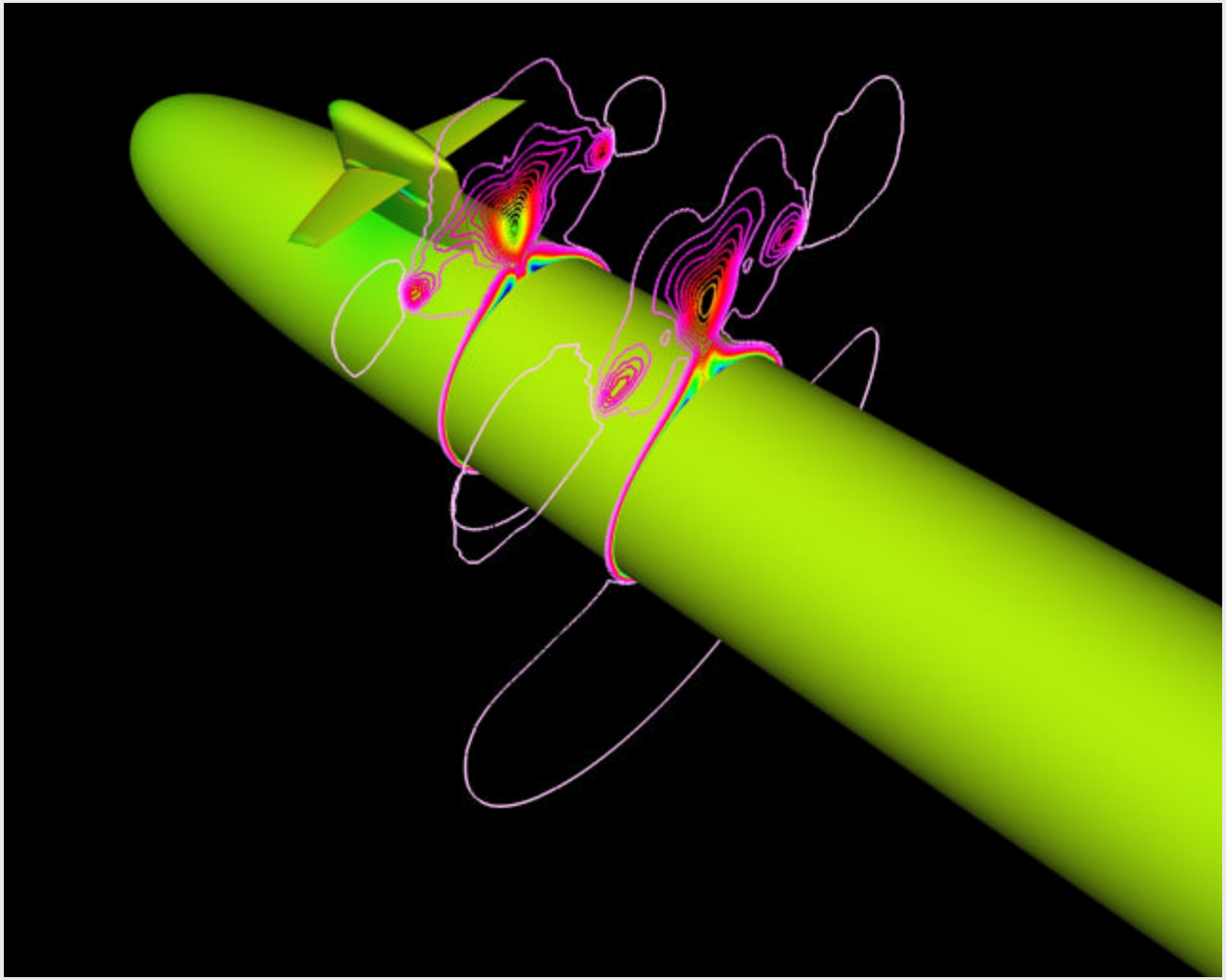






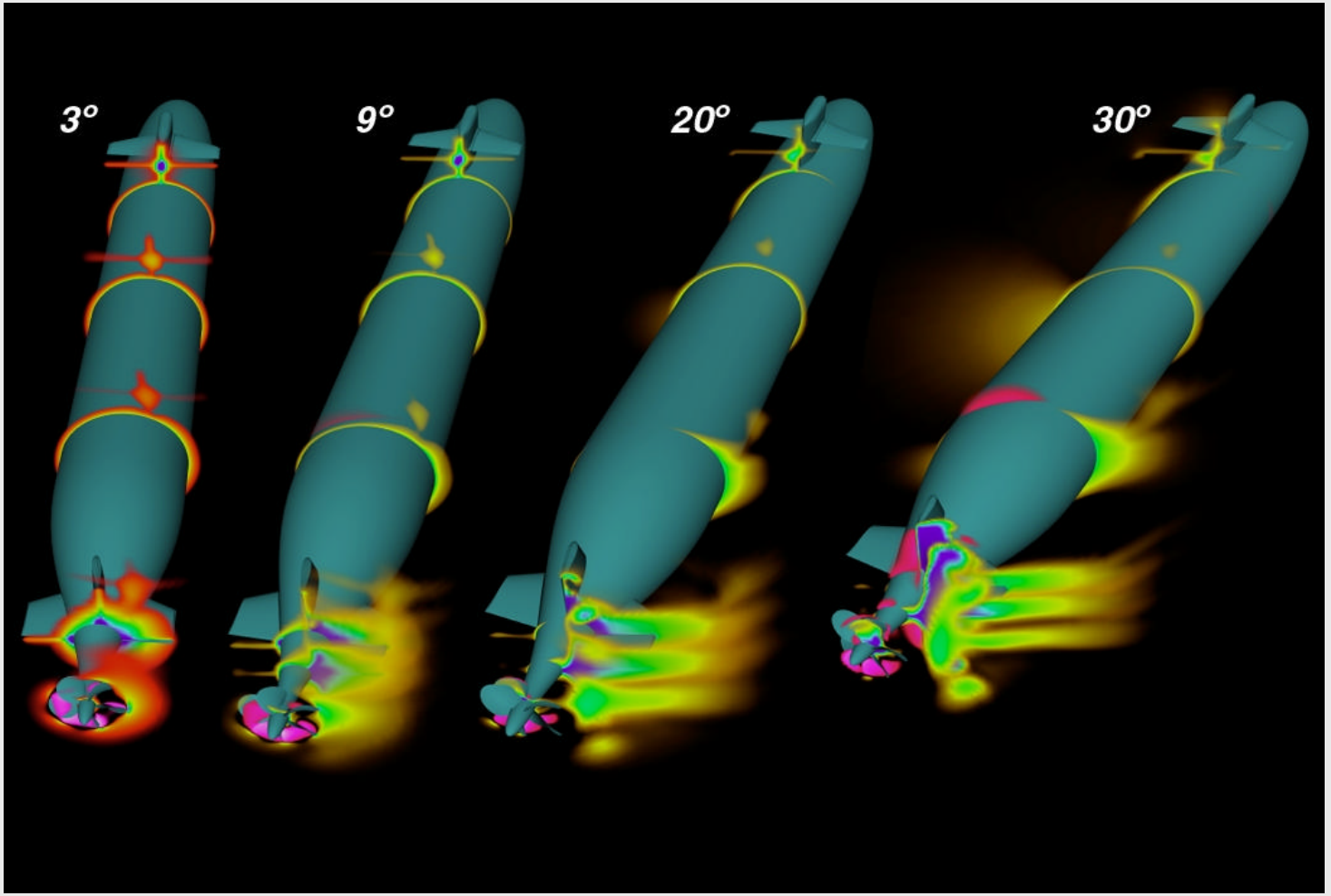
Sailplane-Induced Rising Maneuver

Vortex Wakes Behind Deflected Sailplanes



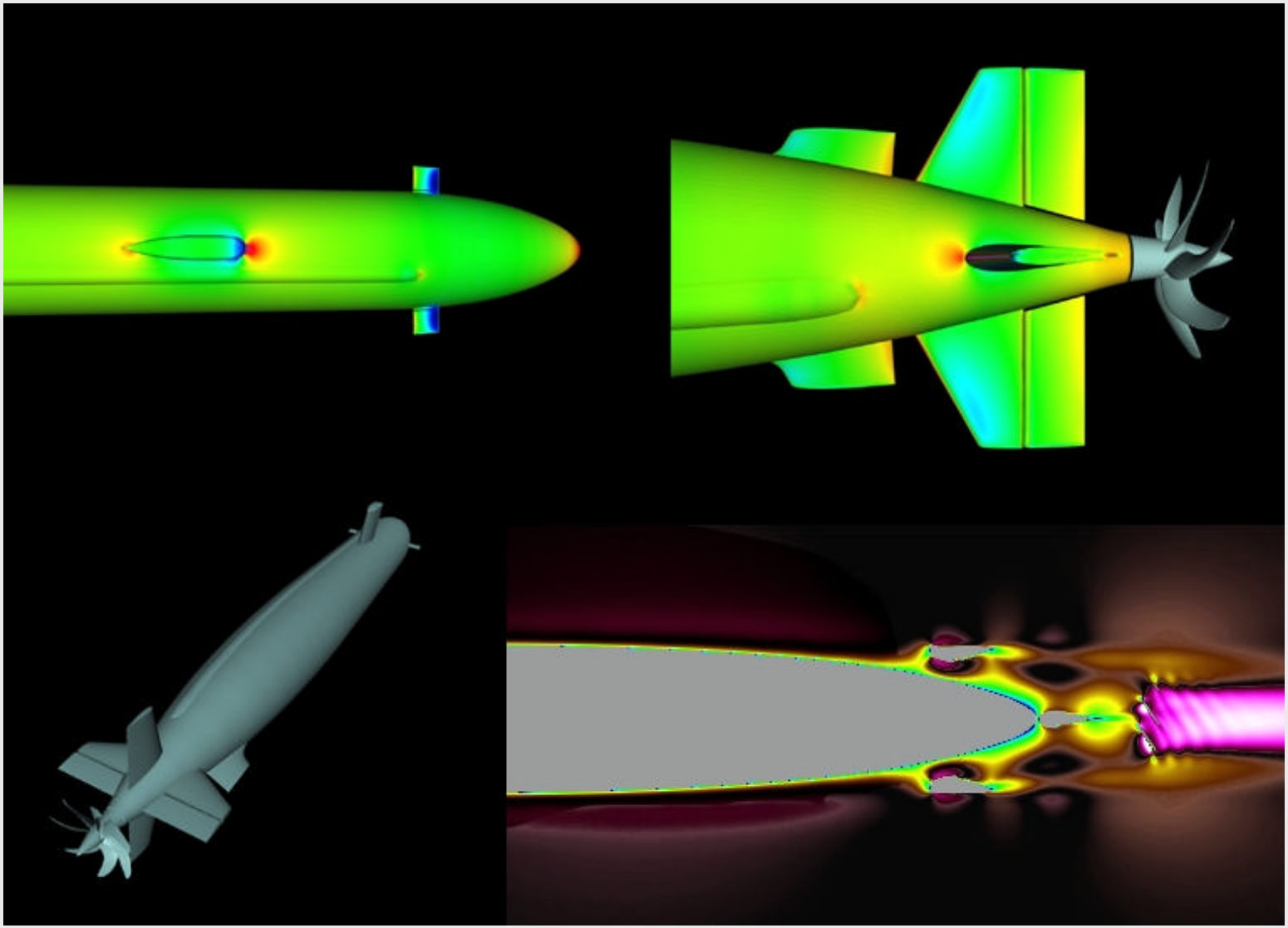
Rudder-Induced Maneuver (Stern View)

10 Deg. Rudder Deflection



Full-Scale Simulation: $Re = 10^9$

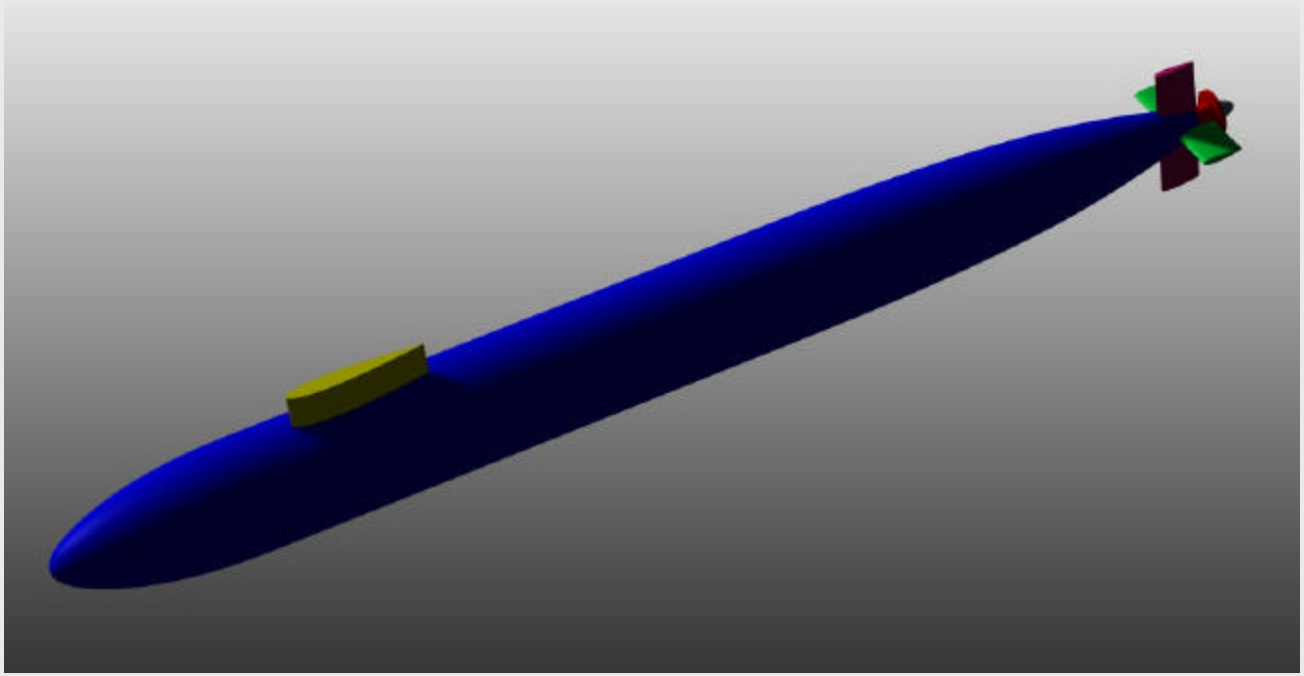
Unstructured Grid ($Y^+ < 1$ at All Surface Points)



FY01 Progress

ONR Validation Experiments Using Radio-Controlled Model

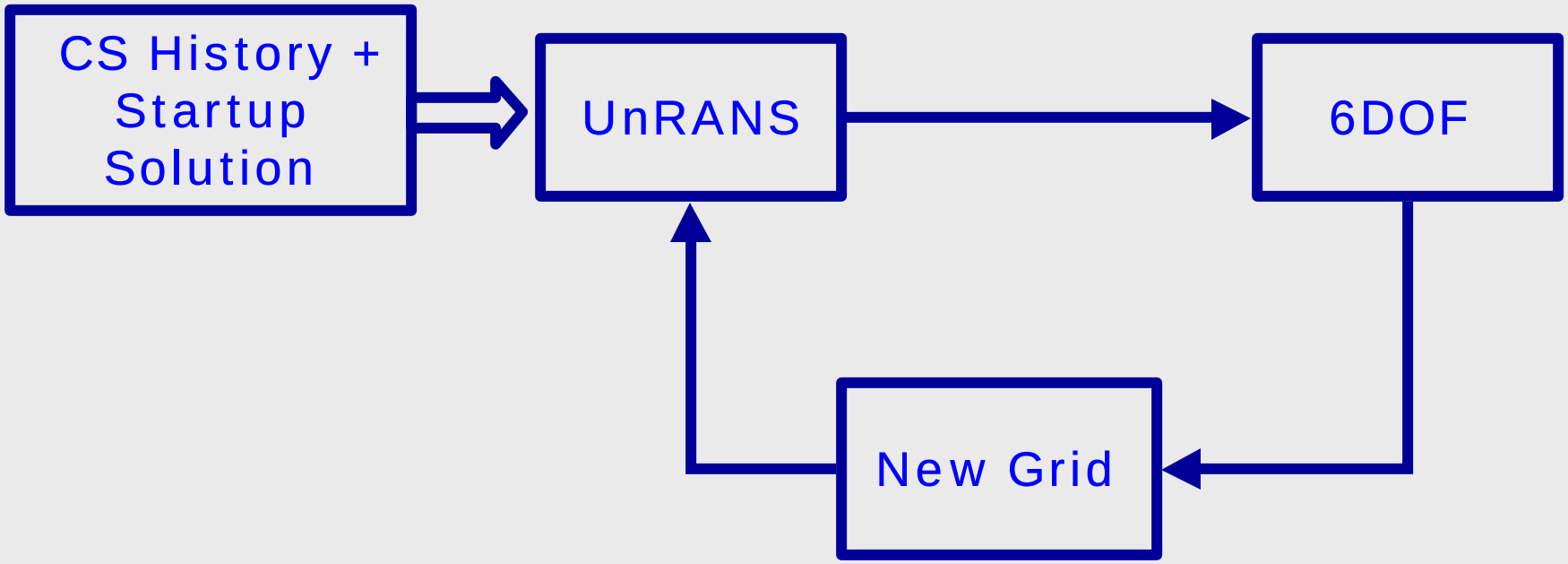
- **MODEL GEOMETRY CAREFULLY MEASURED**
- **HIGH-RESOLUTION CONTROL SEQUENCES**



- **VARIETY OF MANEUVERS EXECUTED**
- **EXTREMELY GOOD REPEATABILITY**

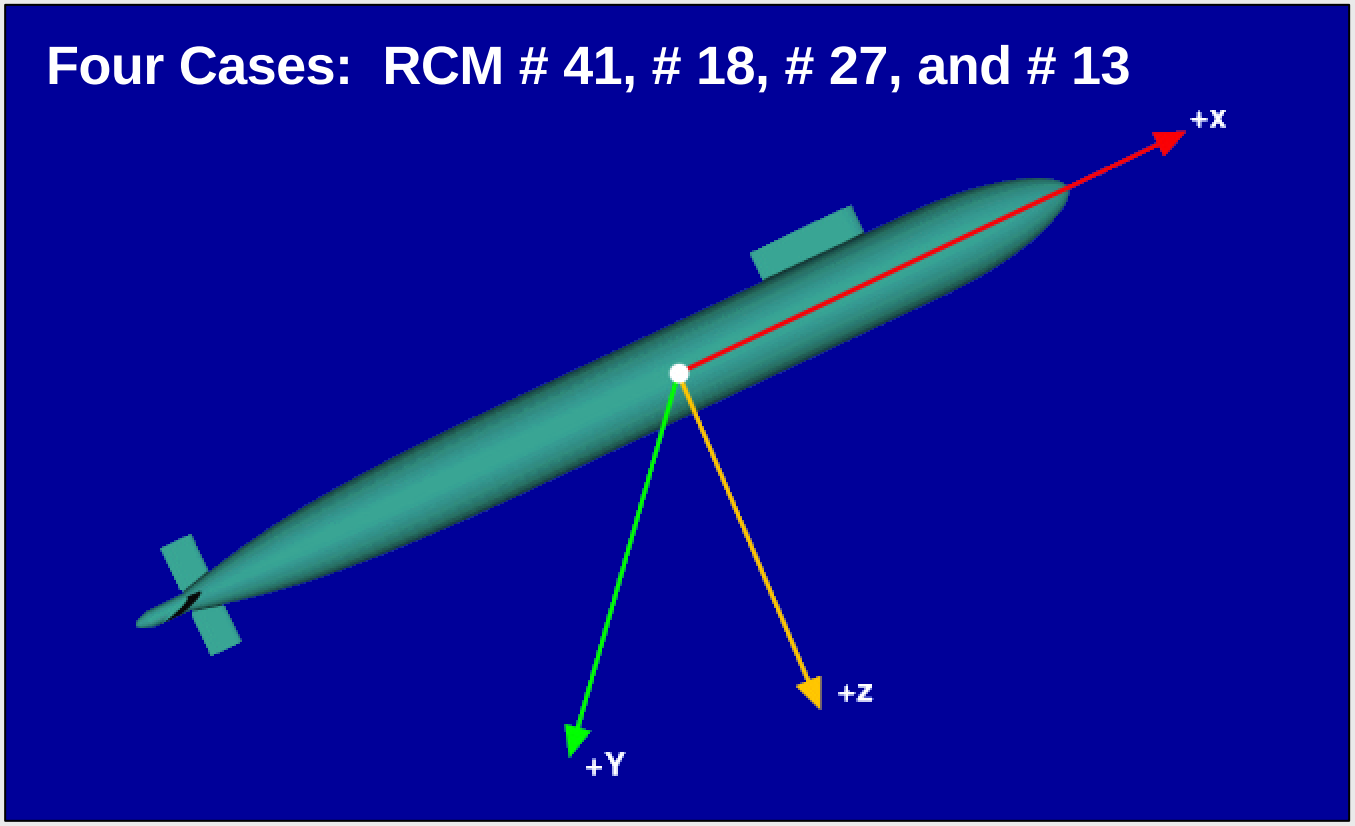
UnRANS: Maneuvering Simulations

Solution Methodology



UnRANS Maneuvering: Reference Frames

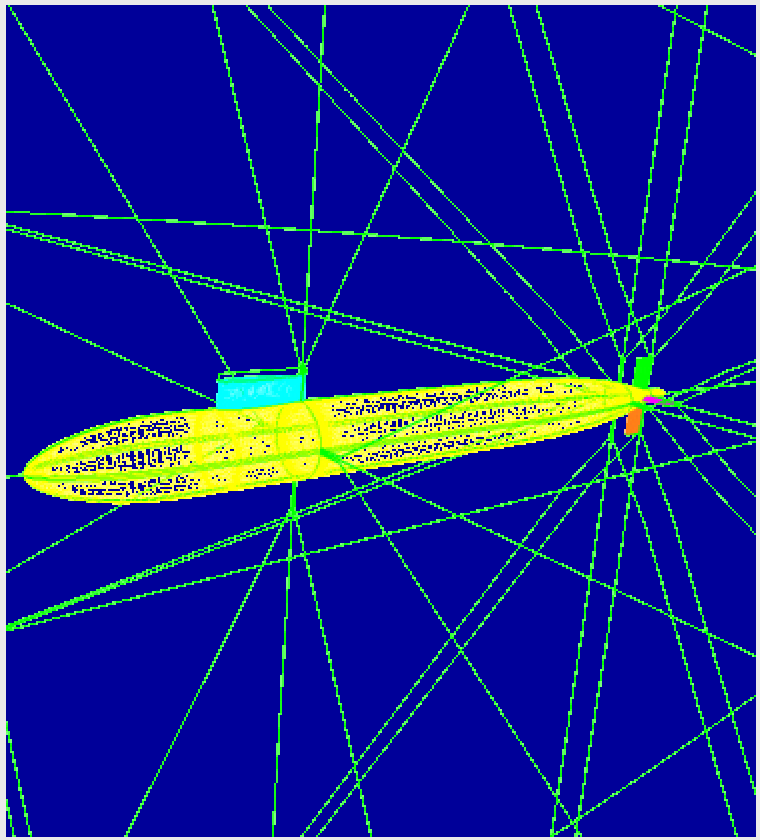
Forces, Moments,Velocities: Relative to Body
Displacements: Relative to Inertial Frame



Vary Dt, Iterations, k-e vs. q-w, Initialization, Smoothed C.S. Motion

UnRANS: Maneuvering Simulations

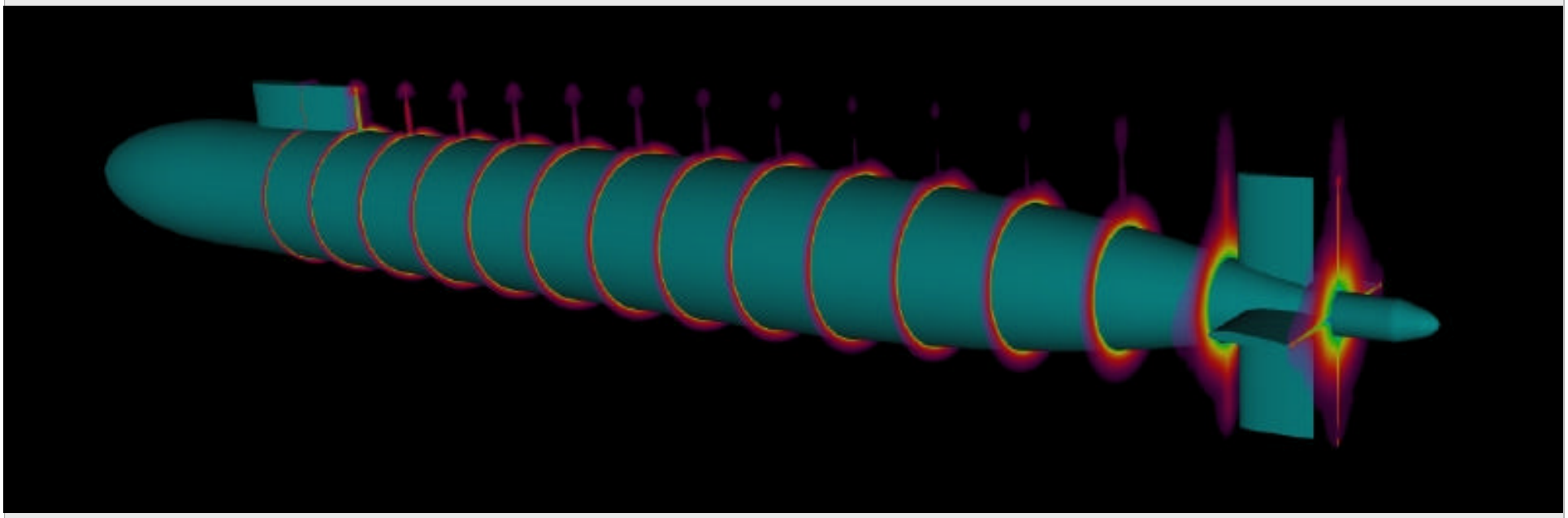
Computational Details



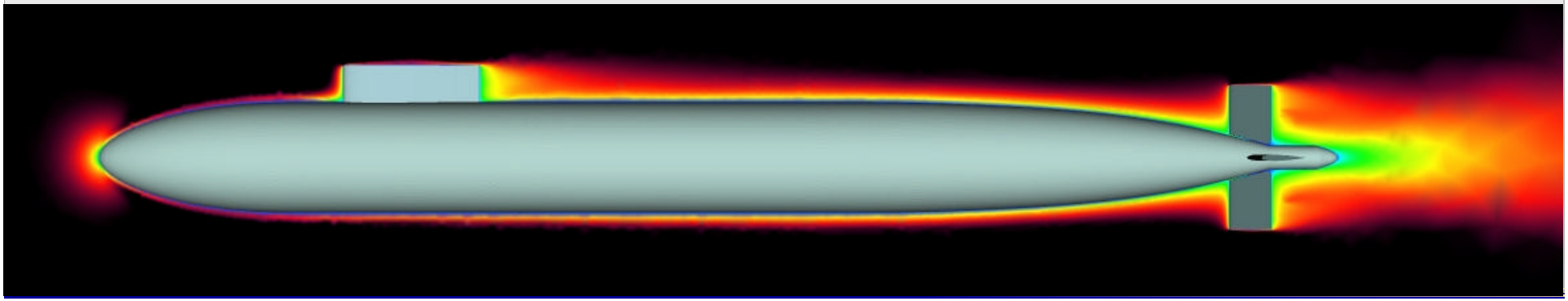
- 6 Million Grid Points, 57 Blocks
- Sublayer Resolution: Y+ < 1
- Body Force Propulsor Model
- Startup Solution: 6550 Cycles
- Time Step of 0.004 Sec. (Physical)
- Simulation Speed:
  0.25 Physical Sec.
  per Runtime Hr.
  on 57 SP-3 Processors

RCM Start-Up Solutions

Structured Grid Solution

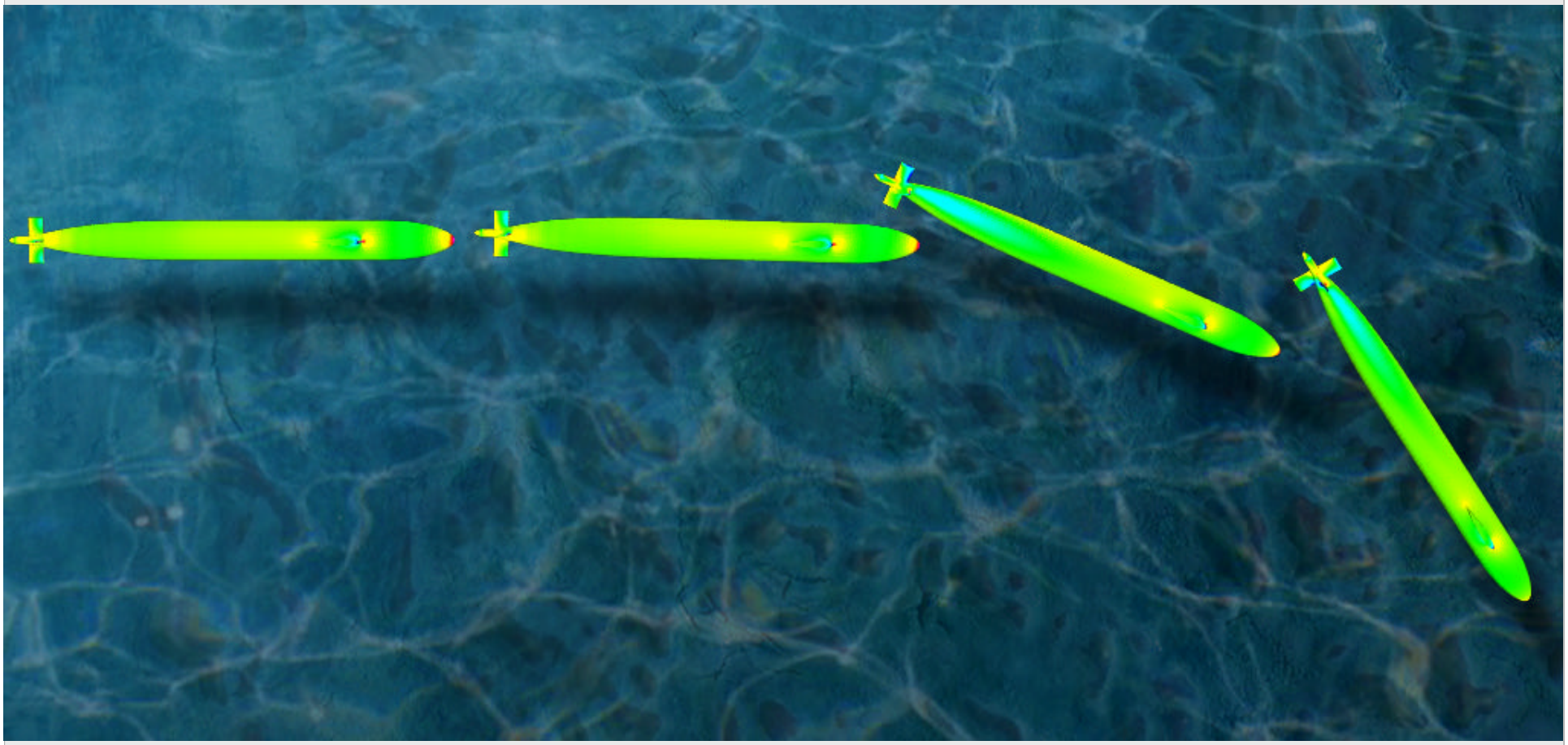


Unstructured Grid Solution



RCM Maneuvering Simulation

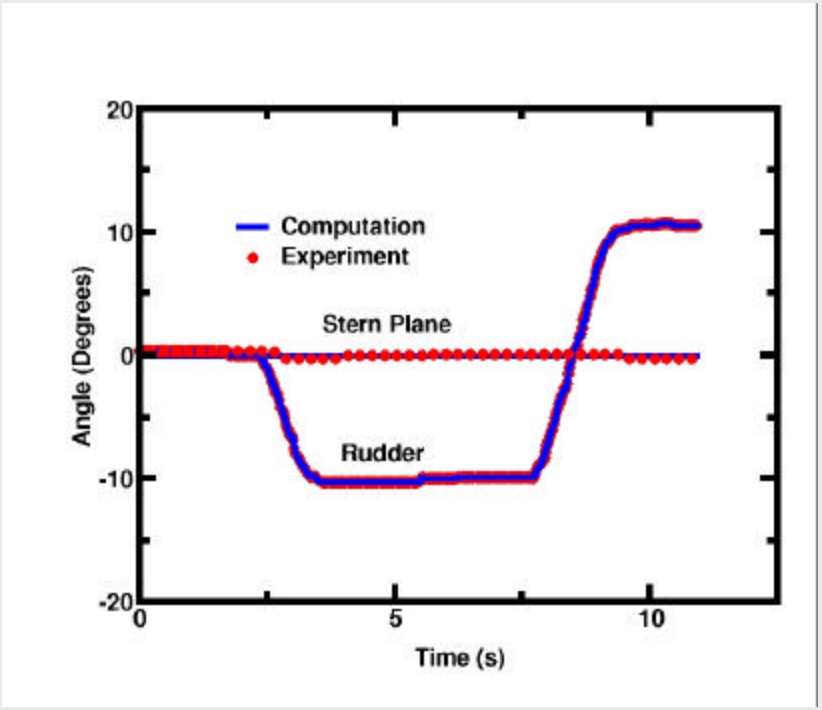
Animation: RCM Maneuver # 41



Validation: RCM Maneuver # 27

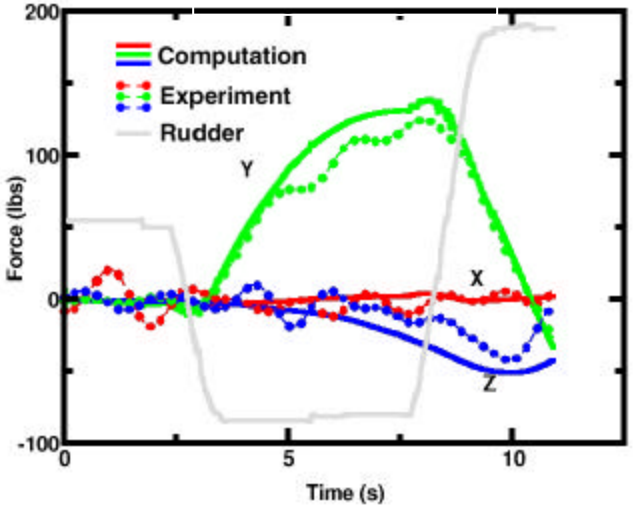
- Horizontal Overshoot (HOVR)
- EYA of 30 degrees
- Rudder Deflection of -10.0 degrees
- 10.9 Second Maneuver at 10 ft/sec

Control Surface Motion

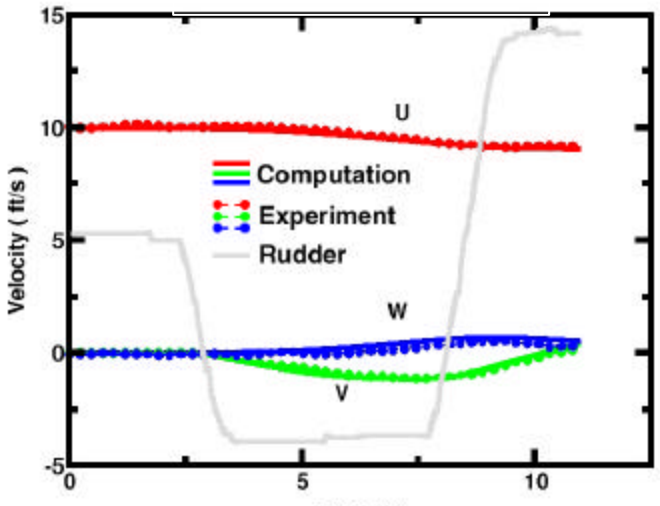


Validation: RCM Maneuver #27

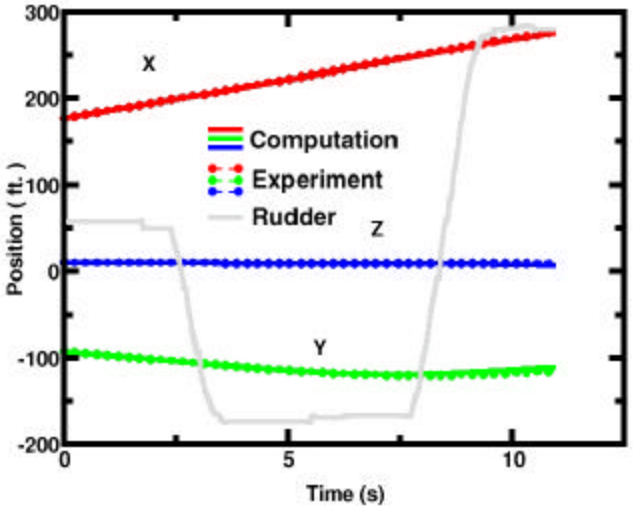
FORCES



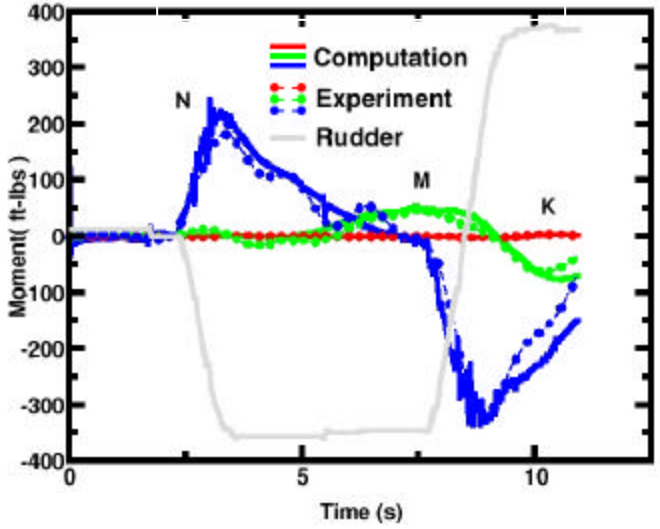
VELOCITY



POSITION

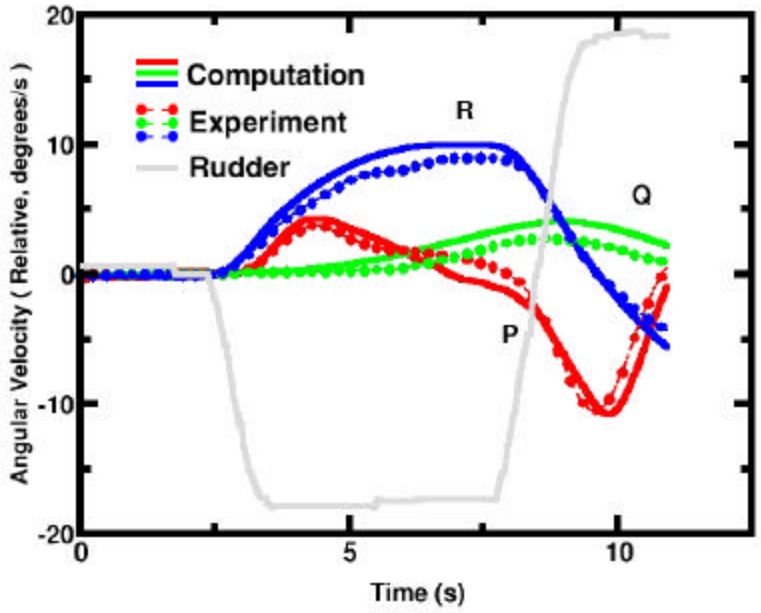


MOMENTS

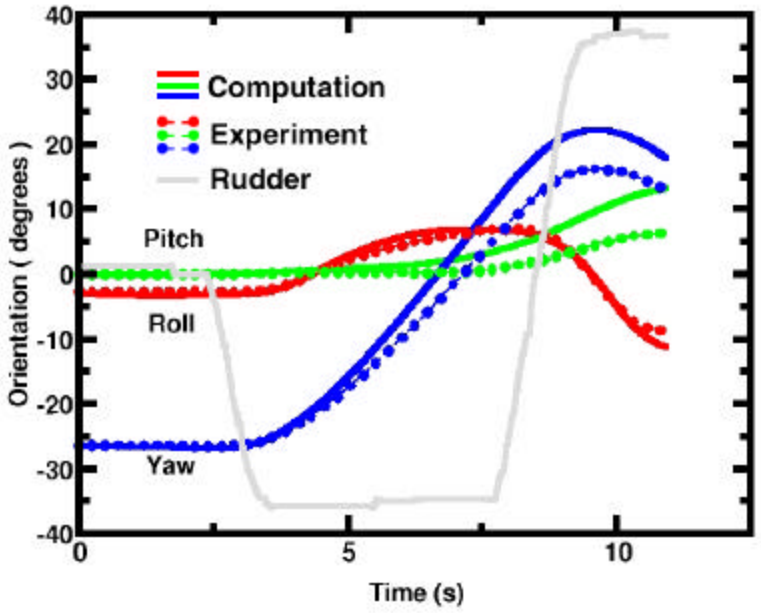


Validation: RCM Maneuver #27

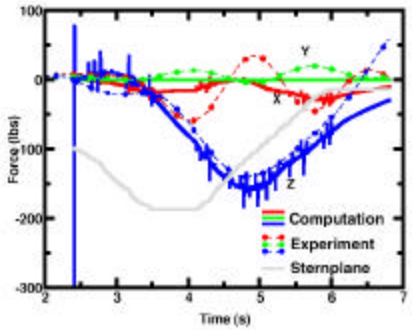
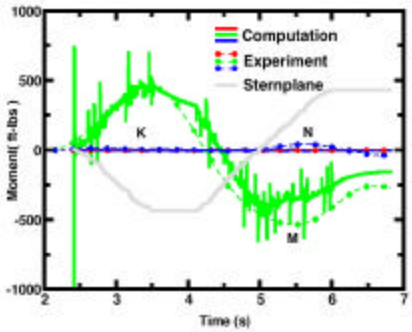
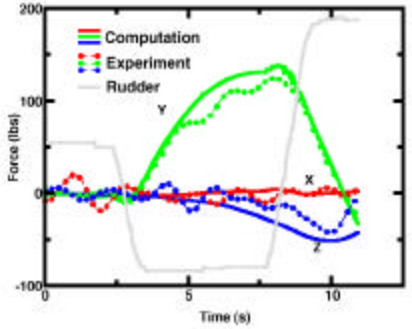
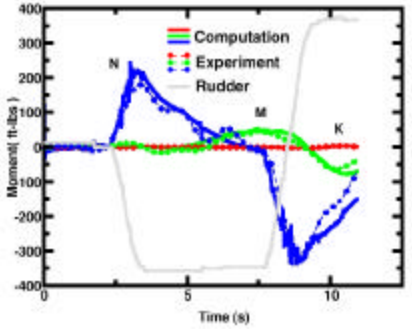
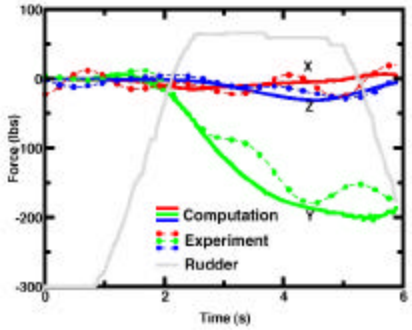
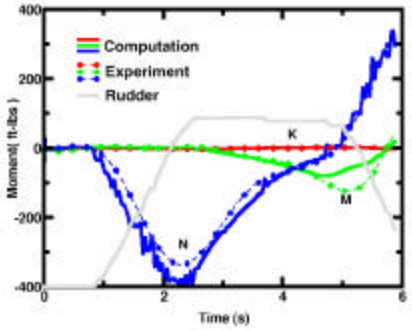
ANGULAR RATES



ORIENTATION



Validation: RCM Maneuver #27

	FORCES	MOMENTS
RCM #41 **Vertical Overshoot** **+/- 25 Deg. Sternplane**		
RCM #27 **Horizontal Overshoot** **+/- 10 Deg. Rudder**		
RCM #18 **Horizontal Overshoot** **+/- 21 Deg. Rudder**		

UnRANS: Analysis and Future Work

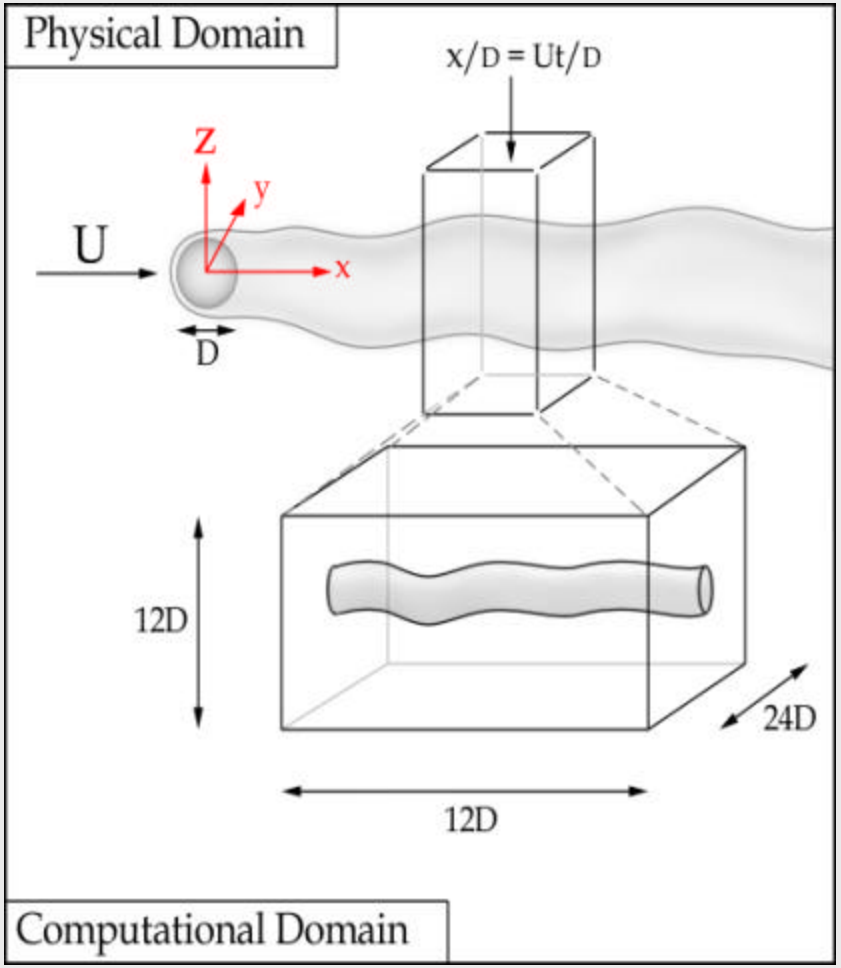
- Accuracy of Forces & Moments
  - Grid Resolution
  - Turbulence Model
  - Unsteadiness Effects
- Grid Refinement
- RCM with Propulsor
- Sensitivity Analysis

LES: Wake Simulations

- **Initial focus: Unsteady structure of the turbulent wake**
  - **Unstratified vs. stratified**
  - **Towed vs. self-propelled**
  - **Laboratory and near-full-scale Re**
  - **Pancake eddy formation**
    - **Vertical fluctuations radiate away as internal waves**
    - **Turbulent production becomes asymmetrical**
    - **Elliptical vortex distribution develops instability**

- **Goal: Radiation of internal waves by the turbulent wake and displacement effects in the littoral zone**

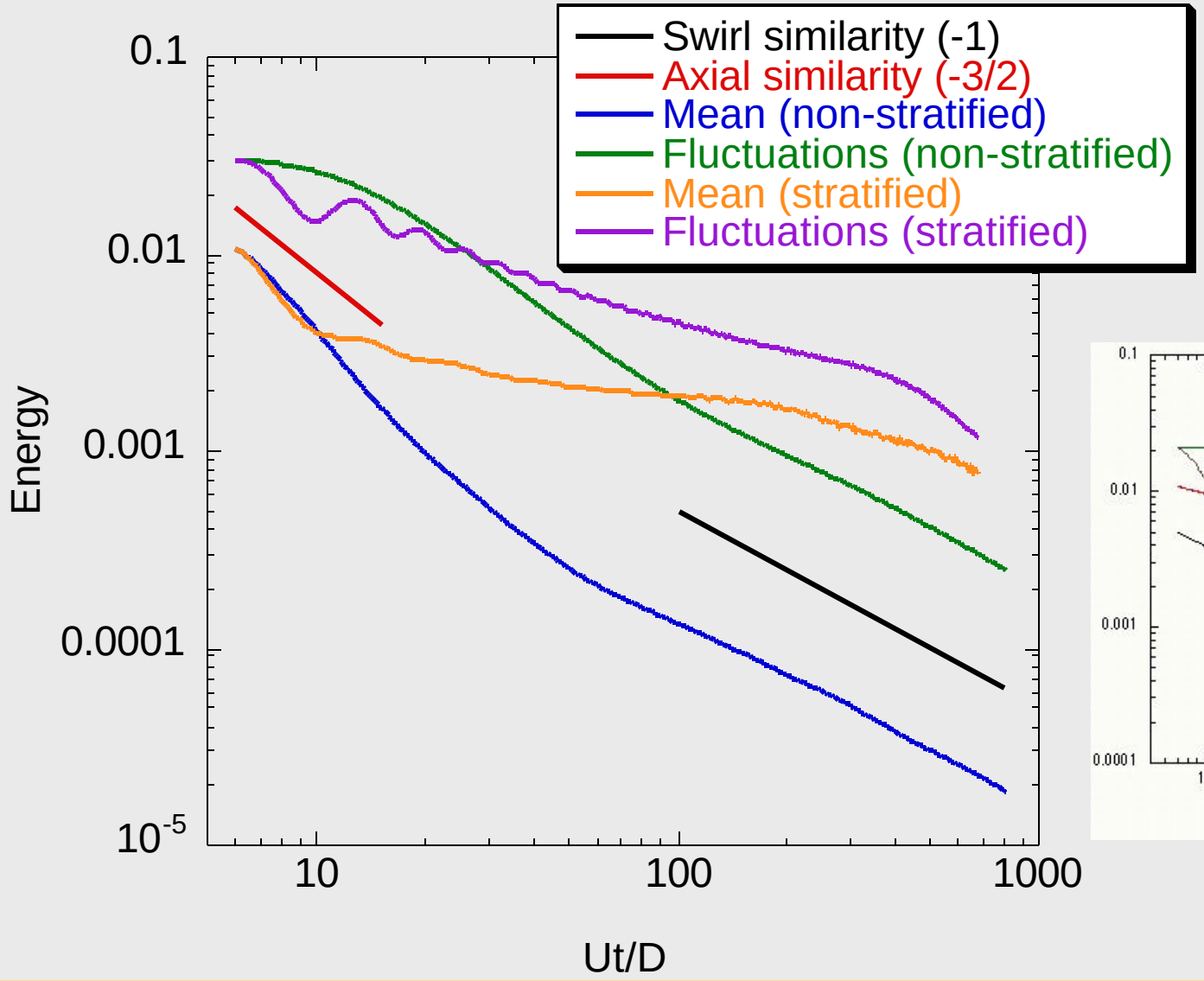
LES: Formulation



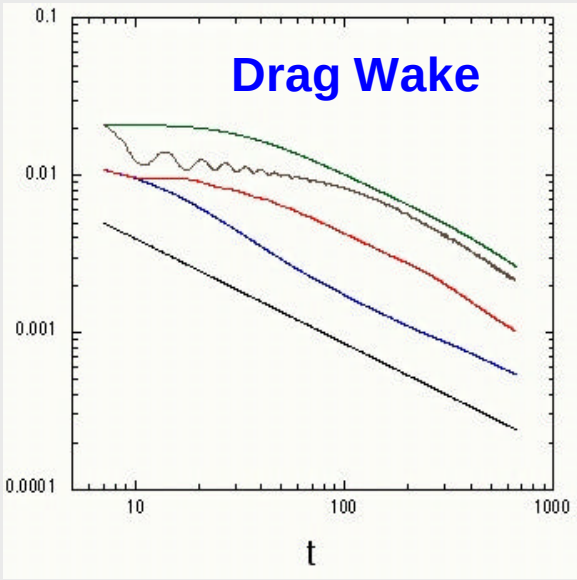
- **Relate spatial evolution of physical wake to temporal evolution of computational wake.**
- **No attempt to directly model the flow around the sphere.**
- **Use mixed model of Bardina, et al. (1984) for subgrid-scale stress tensor.**
- **Grid resolution:**
  - **256 x 512 x 257 (12Dx24Dx12D)**
- **Numerical details:**
  - **FDM, HPF, T3E (128 nodes)**

LES: Wake Simulations

Momentumless Wake Similarity

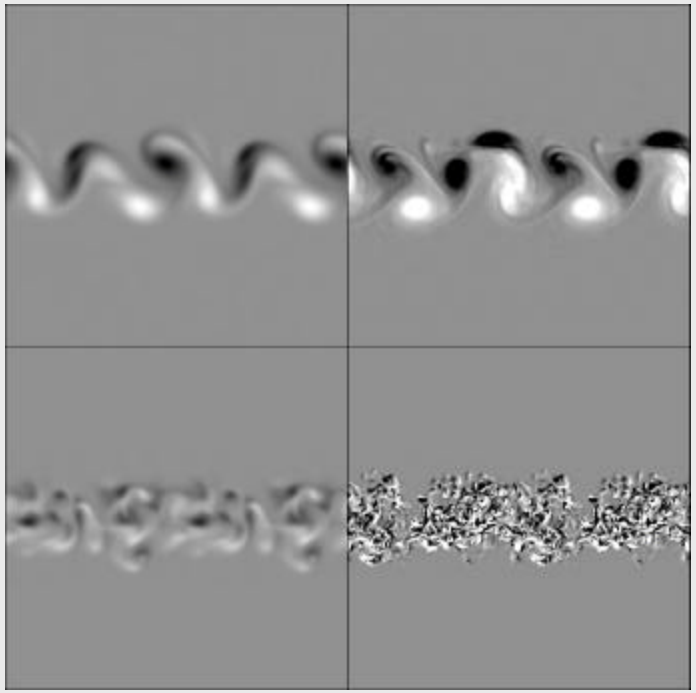


Re = 10^5
Fr = 2



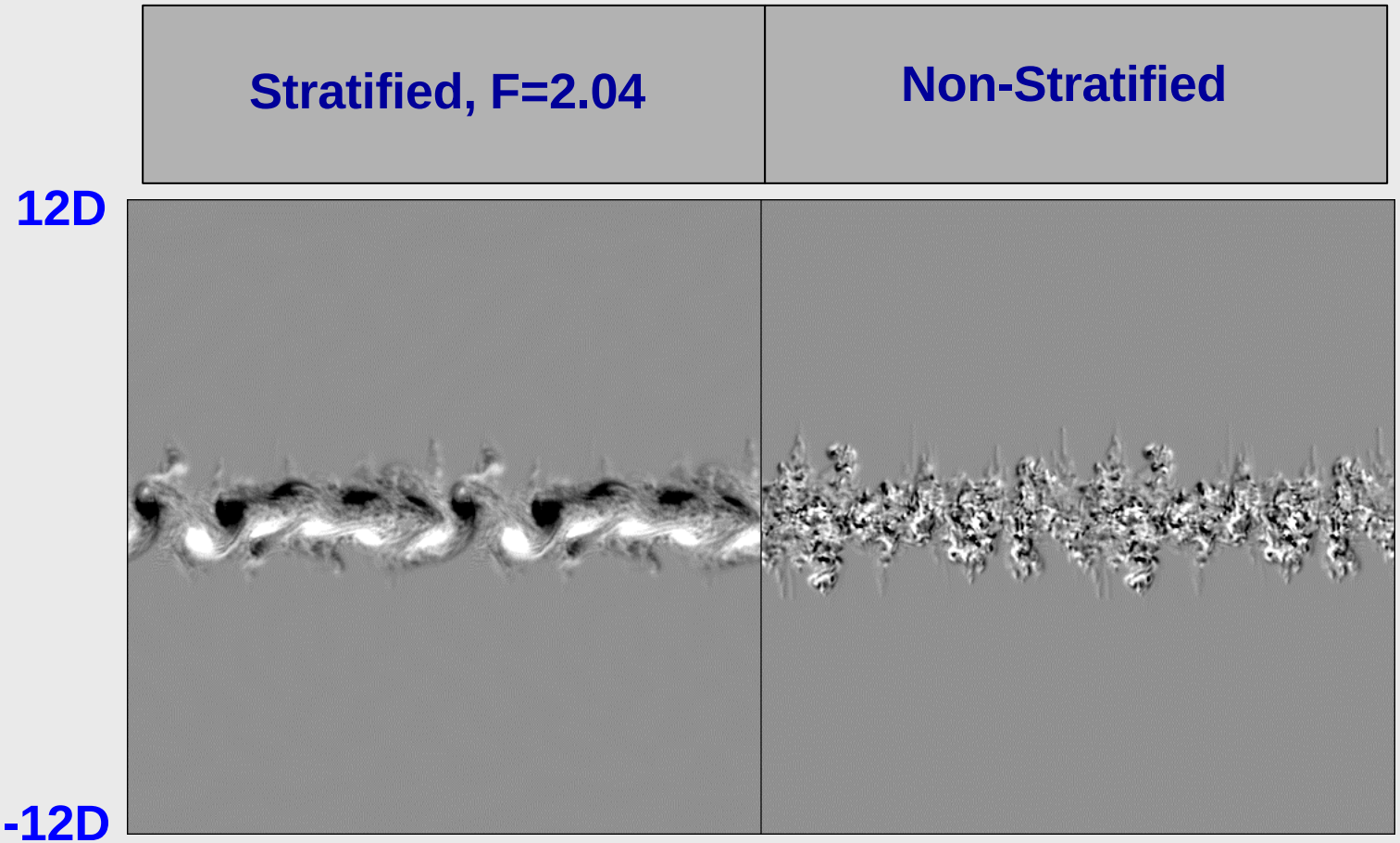
Vertical Vorticity in a Drag Wake

Stratified, Re=5290,Fr=2	**Stratified, Re=10^5,Fr=2**
Non-stratified, Re=5290, Fr=8	**Non-stratified, Re =10^5,Fr=2**



Vertical Vorticity in a Momentumless Wake

Re=10^5

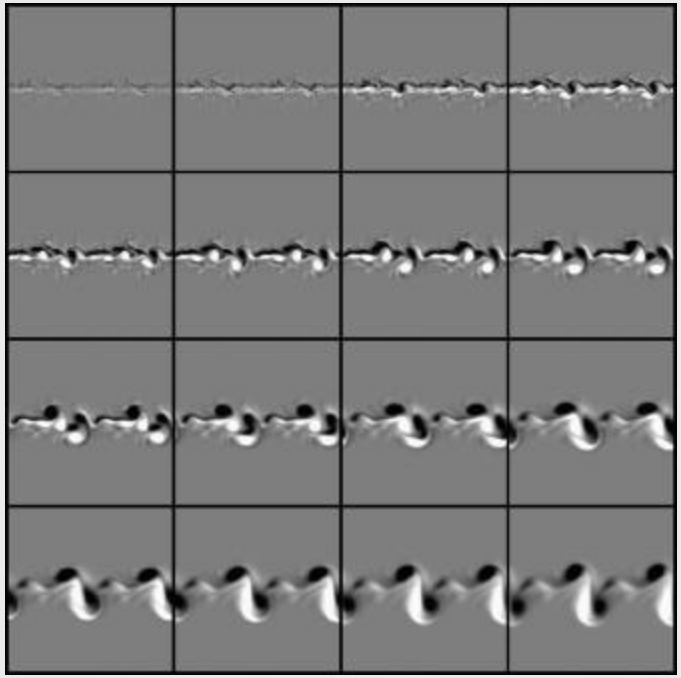


Animation of Vertical Vorticity Component

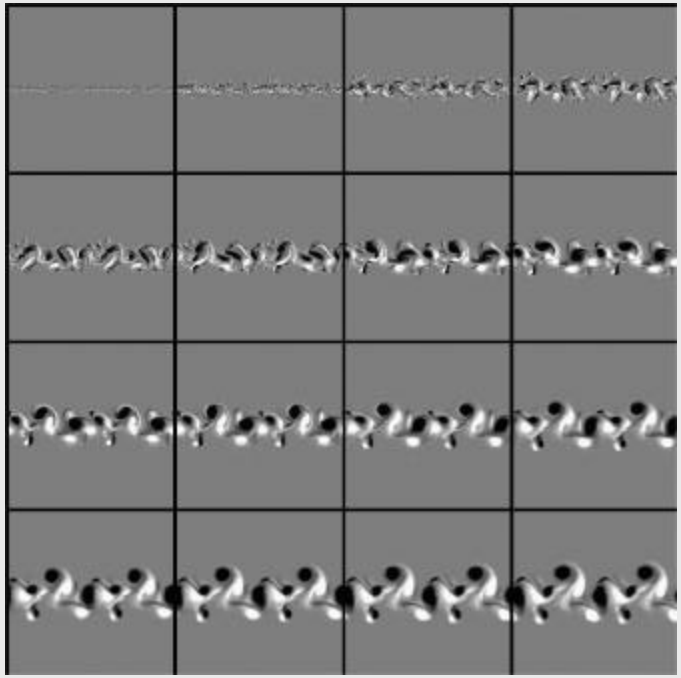
Re = 10^5, Fr = 2

(b)

Drag Wake



Momentumless Wake



Each Frame Represents a Different Distance Downstream of the Body

LES: Conclusions

Drag Wake

- Coherent “pancake eddies” form without the presence of similarly-sized structures in the near field

Momentumless Wake

- Evolution of mean axial velocity is highly dependent on propeller swirl
  - Swirl acts to stabilize axial velocity
- Effects of stratification are more dramatic than for drag wake
- Similar pancake structures, but:
  - More small-scale structure
  - More chaotic

Project Conclusions

Maneuvering Simulations (UnRANS)

Validation of Maneuvering Prediction Capability

Forces, Moments, Velocities, Trajectory, Angular Rates, Orientation

Very Encouraging Agreement with Experiment, Without Propulsor

Far-Field Wake Simulations (LES)

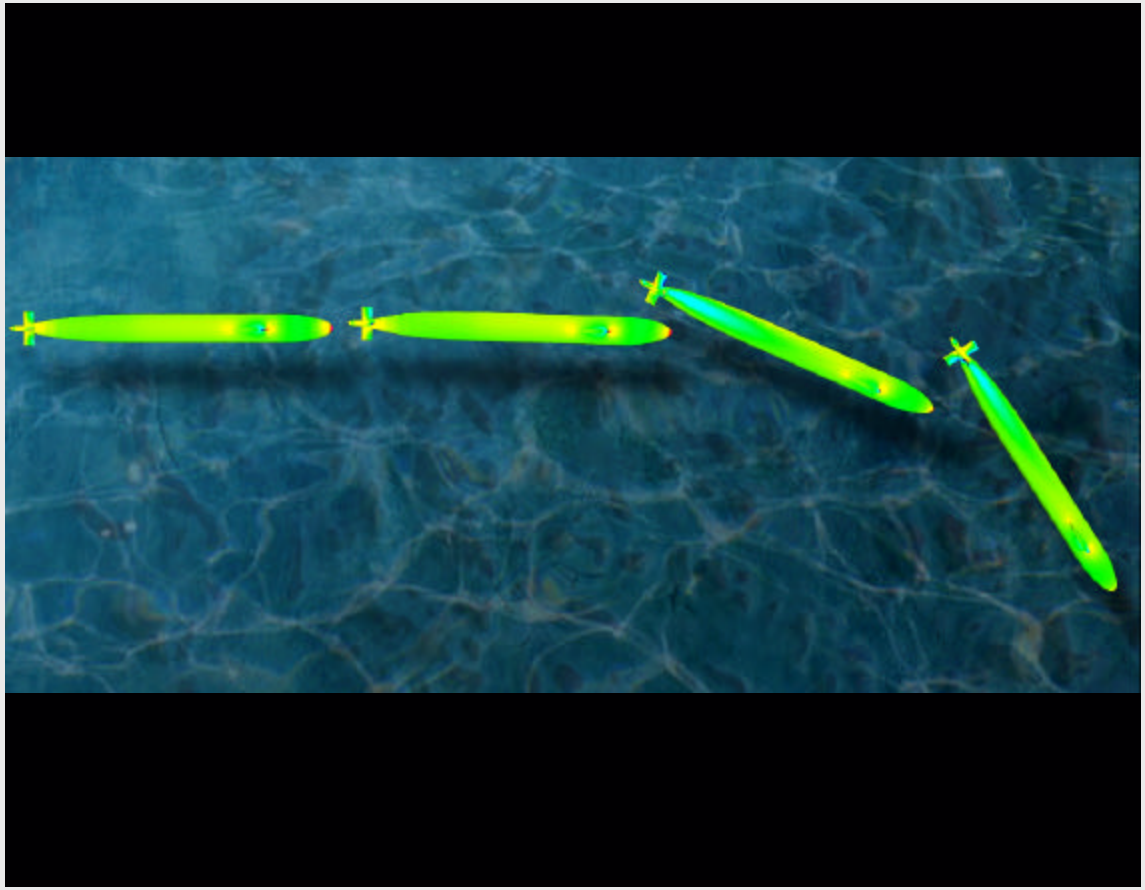
Complex Far-Field Wake Structure and Properties

Drag Wake of Sphere, Momentumless Wake of Submarine

Coherent Structures, Stratification, Wake Decay Properties

Very Encouraging Agreement Agreement with Laboratory Data

Animation of Submarine Maneuver



Animation of Momentumless Wakes

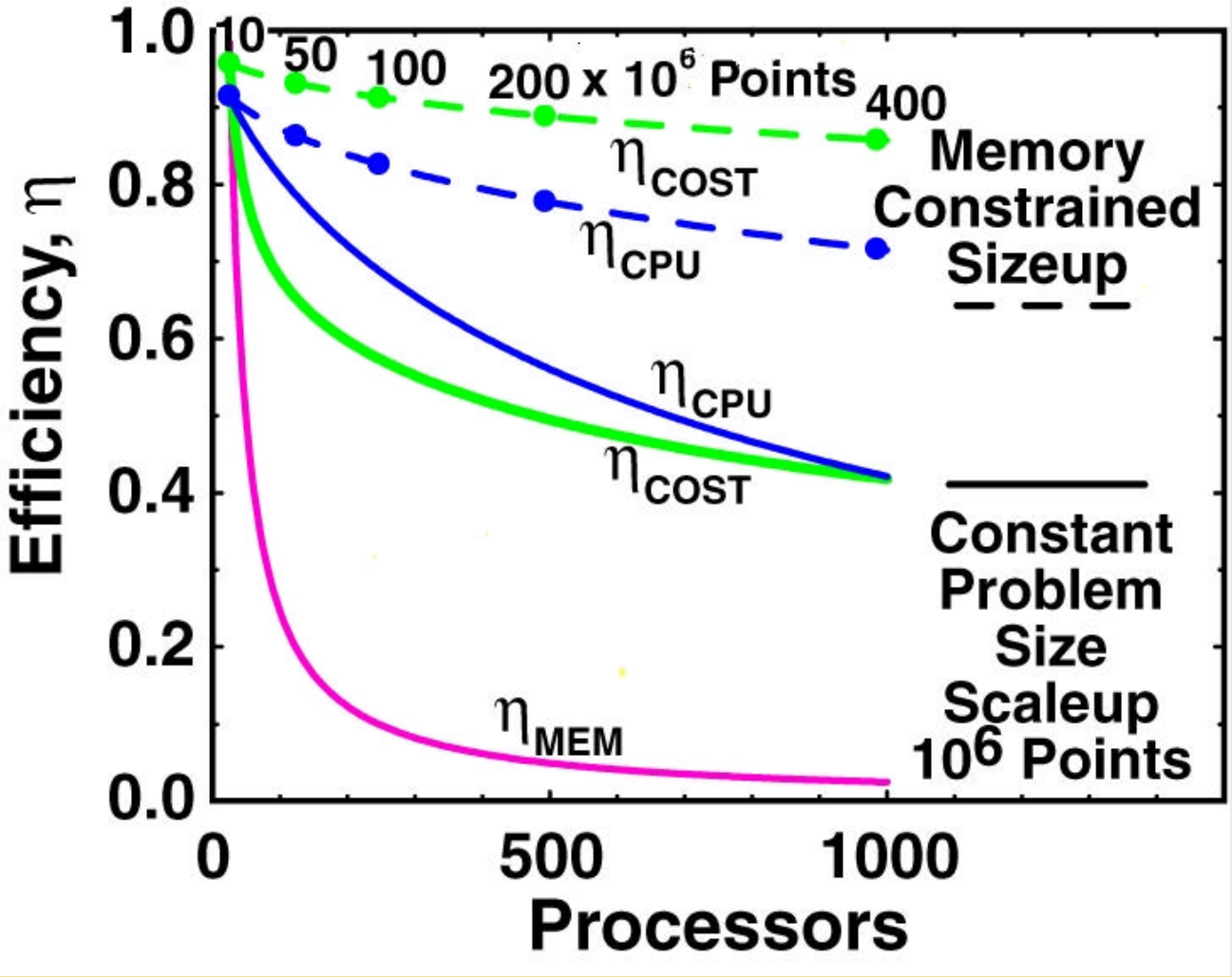
WAKES MOVIE

F = 2
Re = 10^5

F = 8
Re = 10^5

Semi-Empirical Parallel Performance Model

CPU, Cost, and Memory Efficiencies for Typical Current-Generation Values of Processor Speed and MPI Bandwidth



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